PTO 04-3710 French Patent No. 2 687 091

METHOD FOR THE AUTOMATED CONTROL OF CUTS MADE BY A CUTTING MACHINE IN A RIBBON

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UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. JUNE 2004
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REPUBLIC OF FRANCE
NATIONAL INSTITUTE OF INDUSTRIAL PROPERTY
PARIS
FRENCH PATENT NO. 2 687 091

Int. Cl.^{5}:	B 26 D 5/34
Filing No.:	92 01339
Filing Date:	February 6, 1992
Date of Publication of the Application:	August 13, 1993 Bulletin 93/32
List of the documents cited in the search report	Refer to the end of the present specification

METHOD FOR THE AUTOMATED CONTROL OF CUTS MADE BY A CUTTING MACHINE IN A RIBBON

[Procédé de contrôle automatisé des découpes effectuées par une machine de découpage dans un ruban]

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The invention concerns the automated and continuous control of cuts of simple or complex shapes (concave and/or convex), which generally, although not necessarily, are polygonal, and which are made by a cutting machine, such as an "ACCESS" machine which has already been developed by the companies Goldworthy Engineering Inc. and Forest-Line, in the median layer of three-layer composite ribbon. /1*

Such overall polyglonal cuts (with possibly portions of nonrectilinear contours) are easily used for the manufacture of composite panels of airfoils of planes, notably of wings or foil flaps.

These composite panels are obtained by draping, that is by the superposition of cuts made in sheets of fibrous material, for example, sheets of juxtaposed parallel fibers of carbon, which

* [Numbers in right margin indicate pagination of the original text.]

are preimpregnated with a polymerizable resin, such as an epoxide resin. After the superposition with given relative orientations, these cuts are held in place until the time when, by baking in an autoclave, the resin of these cuts polymerizes: one then obtains a monoblock composite panel which, owing to its shape, its very good mechanical properties, and its low weight, can be used in the airfoil of a plane.

Such an operation of draping (stacking of unidirectional layers) thus comprises two successive operations of preparation involving cutting and then laying, which are /2
advantageously carried out independently of each other.

Thus, the companies Goldworthy Engineering Inc. and Forest-Line have developed:

- the above-mentioned cutting machine known under the trade name of "ACCESS," which is an acronym for: Advanced Composite Cassette Edit/Shear System, and

- a cutting machine known under the trade name of "ATLAS," which is an acronym for: Advanced Tape LAying System."

To benefit optimally from this draping machine (DM) in two units, the company AEROSPATIALE has designed and developed software, known by the name of PAOMAD, an acronym for Programmation Assistee par Ordinateur de la Machine A Draper [Computer Assisted Programming for Draping Machine], which has been used since 1985 in its facilities.

A computer-assisted design (CAD) allows the development of an aerodynamic surface in one plane, followed by the definition of unidirectional layers which are capable of reconstituting the desired surface, after draping on warped surfaces. In the field of aeronautics, the Company has elaborated a CADCAM type system, known by the name of AEROLIS, which notably ensures these operations of development of surfaces and which, in collaboration with the software COMPUTER VISION from PRIME, ensures this design phase. This AEROLIS system comprises an interface with the SET standard which allows it to communicate with PAOMAD.

The activities whose automation is ensured by PAOMAD in the case of the draping machine are:

- the determination of the cuts,

- the preparation of the cut and of the draping: DC [digital control] programming, drafting of instruction sheets, calculation of times, and

- the calculation of the consumption of materials.

The functional modules of PAOMAD are schematically represented in Figure 1.

The module "Management of library of pieces" contributes other advantages besides the /3
conventional functions of such a management (list of pieces, suppression, creation or copy of other pieces), namely:

- direct use of the definition files which define layers with the chosen draping range: DM automated draping, manual draping, and

- automatic subtraction of the symmetric piece from a given piece.

The decomposition of a layer into cuts is automatically made (module "determination of the cuts"), integrating the following parameters:

- programmed juxtaposition clearance between two consecutive cuts of the same layer, and

- a programmed offsetting of the junctions of the cuts which belong to layers having the same orientation, to prevent superposition of edges.

The selection criteria for choosing ribbon width can be:

- economical: limitation of the number of cuts and thus of the manufacturing time, and

- techniques: improvement of the quality of the cut as accidental shapes pass by.

The cuts which have been calculated in this manner can be modified with PAOMAD, by an operator who can:

- know the precise geometric definition of a cut,

- blow up a cut of large width into several cuts of small width and vice versa,

- ensure that no fiber has a length less than a given threshold,

- eliminate a cut if it is greater than a minimum achievable size,

- renumber the cuts and intervene on the draping order, and

- impose the direction of draping.

Using the module "banding of the cuts," the piece is automatically decomposed into /4
packets (assembly of layers), then into modules (subassemblies of packets). The cut geometries are then automatically banded into different ribbon widths and in the inverse draping order.

In the case of draping on a simple developable surface (plane, cylinder, etc.), the trajectories are calculated by PAOMAD ("calculation of draping trajectories" module).

In the case of a complex surface, the complex surfaces are calculated by the flattening module of the CAD system, interfaced with PAOMAD using the S.E.T. standard.

From the trajectories and the banding of the cuts, the digital control programs (abbreviated DC) are automatically generated with the help of two post-processes integrated with PAOMAD. The transfer toward the units of the draping machine is then carried out by DDC, that is by "Direct Digital Control."

The functions ensured by the "simulation" module are:

- to simulate the draping: verification that the programming of a piece can be carried out by simulating the laying operation. The graphical representation of this simulation allows the operator to visually control its programming,

- to calculate the consumptions of materials, and

- to calculate the times.

The document US-A-5.006.990 proposes a variant with respect to the theoretical design of the composite pieces and the determination of the layers and cuts to be made, independently even of the carrying out these cuts and the associated laying operations.

The invention is particularly concerned with the cutting operation, so that the steps of design and determination of the drawing of the various cuts to be made will not be further /5
developed. It will simply be assumed that one was able to know, beforehand, how to determine, in digital form, a set of cut drawings to be made.

However, the cutting machine can cause defects to appear in the cuts, because of soiling or wear of the blades. This causes fraying and undercut relief formation. Thus, problems appear when the cuts have very fine tips: the elements for guiding the cut can bend these tips over, and the geometry of the cut is no longer in conformity. This is reflected in excess thicknesses of material, during the laying.

The inspection of these defects is currently carried out by an operator who visually evaluates whether or not the cut has a defect. This method of inspection requires considerable experience on the part of the operator, together with much intuition, because the operator does not know the geometry of the cut beforehand.

The drawback of this control is that it is repetitive and tedious, and it requires increased vigilance of the operator. However, fatigue during visual inspection results in operator errors (these are undetected defects), which have a detrimental effect on the final quality of the manufactured pieces.

The object of the invention is to overcome these drawbacks by proposing a method and a device which make it possible to omit any human visual control, and which make it possible to conduct this control of the cuts for the detection of defects, in an automated, and thus very reliable, manner, without requiring a reduction in the advance speed of the ribbons (and thus of the cutting rate).

For this purpose, the invention proposes a method for controlling successive cuts which are at least approximately polygonal and made by a cutting machine in a ribbon based on data on successive theoretical cuts, according to which:

- one advances the cuts over a contrasted background,
- one acquires a succession of images of a field encompassing the entire width of the /6
ribbon, at a frequency such that two successive images encompass the zones of advancing ribbons which partially overlap,
- one binarizes the image by associating with each point one of the two values, depending on whether the luminance of the point is greater or less than the threshold,
- one applies an extraction of contour by Freeman coding to this binarized image,
- one identifies each contour,

- one divides the image into as many processing windows as there are closed or unclosed contours,
- one produces a polygonal approximation of each closed or unclosed contour,
- one vectorizes each segment of the polygonal approximation by determining at least one angle between two successive segments,
- one compares the succession of the angles measured in the polygonal approximation to the succession of angles of a polygonal approximation of the theoretical cut having the same identification,
- one detects a defect if one does not find the succession of angles measured in the succession of the angles of the polygonal approximation of the theoretical cut having the same identification.

The proposed solution is a vision system which is computer-assisted and which detects, in real time, the defects inherent in each cut, and which, if applicable, alerts an operator, for manual restart. This system replaces human visual control, by the acquisition, processing and interpretation of the images of the cuts. The advantages of this device are the autonomy of the machine, an increased reliability compared to human control, and thus automation of the control.

The vision system comprises a camera (for example, PULNIX TM765) with a CCD matrix sensor (charge couple device), placed above the ribbon of the cuts. It is located in the /7 downstream part of the machine, after the cutting zone, and immediately before the winding on the receiving spool. This sensor supplies a signal to the video standard CCIR 50 Hz, which is transmitted to a specialized processing card located in a microcomputer. This card digitizes the signals, by means of an analog-digital converter and it forms, in practice, signals on 256 luminances (gray levels). These images are stored in a memory of the specialized card, to be processed by software.

The treatment consists in extracting, from the images, pertinent data, that is data which can be interpreted later: it consists of the contours of the cuts which are modeled in the form of segments, by means of an algorithm of polygonal approximation (cord method). A parameter allows the regulation of the fineness of the approximation. When this regulation is too fine, superfluous segments are generated. A "cleaning" algorithm then allows the elimination of the unwanted segments.

The data obtained by image processing are then compared to the theoretical model of the cut, which data is contained in a file which was generated beforehand by CAD (for example, using the software PAOMAD developed by AEROSPATIALE), to decide whether a cut has, or does not have, one (or several) defect(s). Given that this control is separate from the digital control, it is necessary to ensure a count of the cuts using the vision system, to be able to compare the cut during the control with the corresponding cut in the CAD file. This count takes

into consideration the regression of the ribbon which is carried out by the "ACCESS" machine during the removal of wastes, due to the mechanical hysteresis. This is carried out by an analysis of the gray levels of two columns perpendicular to the advance of the ribbon, whose spacing must be less than the minimum distance separating two consecutive cuts and greater than the distance of regression of the ribbon. /8

This method for comparison works well for cuts with simple polygonal shape. However, it is much less effective when the geometry of the cut comprises curves such as arcs of a circle, portions of an ellipse, etc. This is explained by the fact that the polygonal approximation of the curved parts is different from the approximation of the curves made by the CAD system. The consequence is that the system always detects defects in this case.

This is the reason why, in the case of cuts which are partially curved, simultaneously with the structural approach of detection of defects, a method of recognition by neuronal networks can be used. This approach is based on computerized modeling of the human nervous system. It is based on the concept of learning by reinforcement or decrease of the weights assigned to connections between neurons as a function of their use. The first phase, called the learning phase, consists in giving the network representative cuts with and without defect, in a balanced proportion: the network "learns." During the second phase, called the classification phase, the network recognizes unknown cuts owing to its capacity to generalize.

The coupling of the comparison method with the method using neuronal networks, by means of decision rules, forms a hybrid system which supplies pertinent results which, regardless of the geometry of the cut, are much superior to those obtained by each one of the methods used separately.

According to the preferred arrangements of the method of the invention, which can optionally be used in combination:

- in addition:

· one constructs a network of neurons with n inputs, three layers and one output,

· one causes this neuronal network to undergo learning, using a set of defect-free cuts, /9
and a set of cuts with defects, where each cut is characterized, with polygonal approximation, with N magnitudes applied with N inputs,

· simultaneously with the steps of vectorization and comparison, one applies N magnitudes of each polygonal approximation to this network of neurons,

· and one detects a defect if a predetermined decision rule is satisfied, which combines the results of the comparison operation and the output of the neuronal network,

- where the N magnitudes which characterize each approximation are N values taken on by the discrete Fourier function applied to the curvilinear abscissa for frequencies 1 to N,

- N is 10,

- the input function of each neuron is a linear function of the inputs, each having its own weight, where the activation function is of the sigmoid type and the output function is the identity function,
- the cuts without defects which are used for the learning phase have curved sections,
- one of the decision rules is: "the cut is validated without defect if the number of segments of a cut by image processing is much lower than the number of segments of the theoretical cut and if the result obtained by a neuronal network is good,"
- each contour is identified by counting cuts which pass through the field of the camera,
- the speed of advance of the ribbon being at most 30 m/min, the acquisition time for binarization, contour extraction, polygonal approximation and comparison is less than 0.5 sec,
- the cuts are made in a composite of carbon fibers which are unidirectionally applied to a white support, and
- after vectorization, and before comparison, one proceeds to replacing by a unique vector any pair of successive vectors whose angular separation is less than a predetermined threshold. /10

Objects, characteristics and advantages of the invention will become apparent in the following description which is given as a nonlimiting example, with reference to the drawings in the appendix in which:

- Figure 1 is a diagram of the known principle of the process which leads from a base surface to be made with digital control programs intended for a cutting machine and a laying machine, respectively, and showing the functional modules of PAOMAD,
- Figure 2 is a diagram of the principle of a cutting machine, which comprises a device for controlling the cut according to the invention,
- Figures 3A-3D represent examples of defects to be detected,
- Figure 4 is a representation of the SADT type of the draping operation,
- Figure 5 is a representation of the SADT type of the control operation which is included in the draping operation,
- Figure 6 is a diagram of the image acquisition and processing architecture,
- Figure 7 is an example of a contour portion,
- Figure 8 is a representation of a FREEMAN coding of connectivity of order 8,
- Figure 9 is a schematic view of the elements of the control system which are intended to scrutinize the ribbon during advance,
- Figure 10 is a schematic view of an image containing two processing windows,
- Figure 11 is a view of a cut which is entirely contained in the image,
- Figure 12 is a view of the cut of Figure 11, which is incompletely contained in the image,

- Figure 13 is an optimized algorithm for the comparison of the angles measured with the theoretical angles, /11

- Figure 14 is a schematic representation of a neuron,

- Figure 15 is a schematic representation of the architecture of a neuronal network in several layers,

- Figure 16 is a diagram of a linear neuron with thresholds,

- Figure 17 is a diagram of a nonlinear neuron,

- Figures 18-1 to 18-18 are examples of cuts without defects, on which control tests were carried out in comparison with the theoretical data,

- Figures 19-1 to 19-9 are examples of cuts without defects on which control tests were carried out in comparison to the theoretical data, and

- Figure 20 is a partial diagram of the method of the invention for controlling cuts comprising curves, which involves a hybrid strategy of interpretation of polygonal approximations.

Figure 2 is a schematic representation of a cutting machine 1 in conformity with existing machines of the "ACCESS" type, which, however, comprise a device for controlling the cut and the detection of defects, which is schematically represented at 30.

This machine carries out polygonal cuts having a convex, concave, or complex shape, in the ribbon 2 made of preimpregnated carbon (composite sheet, thus a sheet with unidirectional fibers stretching in the direction of the ribbon), for example, having a thickness of 127 μm, a width of 50, 75 or 150 mm, and a length of 250 m. This ribbon 2 is sandwiched between two separators: a sheet 3 made of clear paper (in practice a white sheet) and a transparent sheet 4, made, for example, of polyethylene terephthalate. The entire assembly is stored on an input spool 5, which is fixed to the cutting machine. A receiving spool 6 for receiving the cuts, which is fixed to the other end of the machine, allows for a system of continuous unwinding-winding. /12

The ribbon 2 and the separators 3 and 4 pass over the guidance plates 7, and they are led into the cutting zone. The two separators are then removed and recovered separately in storage cassettes 8 and 9. The preimpregnated ribbon is cut with two carbide blades 10 and 11, which are independent of each other. Each can move in a direction perpendicular to the direction of advance of the ribbon, and pivot about its principal axis. It is the combination of these movements and the advance of the ribbon which makes it possible to make cuts having a complex geometric shape, although the ribbon is moving in only one direction. The cutting can take place with a very rapid oscillatory movement of the blades, from the bottom upward. Blades 12 and 13, forming an anvil, are associated with the former blades.

When the cutting is finished, the cut is placed again between two new separators (paper 13 in the spool bearing the reference numeral 14 and transparent sheet 15 in the spool bearing the

reference numeral 16), in the downstream driving device, and stored on the recovery spool 6. Each cut is spaced from the preceding one by a distance which was fixed beforehand; this spacing is possible due to a relative movement of the downstream driving device compared to the upstream driving device.

When the profile, before a cut, is different from the back profile of the preceding cut, a waste cutting is formed and removed; it is selected by the descent of a boring shoe 17, for example, with mechanical action, here in two parts, which is held between two ribbons and directed toward a storage cassette 18. This descent of the boring shoe applies tension to the ribbons. To relieve this tension, the machine carries out a slight regressive movement of the ribbon by 3 mm, and then an advance by 4 mm, at constant speed.

Each cut is automatically marked with a punch 19; here this mark in the transparent sheet /13
serves to locate the cut, during its use on the "ATLAS" laying machine. It validates, a priori, this cut as lacking any defects (absence of defect during the cutting operation). If this is not the case, an operator closes the mark again with transparent scotch tape. This cut will not be taken into account later. On the other hand, the operator has to manually relaunch the manufacture of this cut and of all those which may have been made in the meantime.

The speed of advance and the application of pressure to the ribbon in the inlet are controlled by the motor 20, while the digital control is made with a coder 21.

The cut composite ribbon is driven by a device schematically represented at 22 and, after again sandwiching these cuts, the holding of the three-layered ribbon is ensured by the weight system bearing the reference numeral 23.

The speed of displacement of the ribbon is 0-30 m/min. The minimum length of the cuts is 45 mm, and the maximum length 8 m.

The polygonal cuts are then gathered to form one piece, which is made by the "ATLAS" laying machine, not shown, which proceeds by stacking layers of cuts. The entire combination is then polymerized in an autoclave, to obtain the desired piece. These pieces are panels, airfoils, foil flaps, etc., constituting a part of planes.

The preceding elements, as they are known in themselves, are not detailed below; the invention concerns the control block 30, located on the machine, before the winding of the cuts on the receiving spool 6 which is intended to be then mounted, at an appropriate time, on the laying machine.

It is important to note that the invention is not concerned with a dimensional control of the cuts, rather it concerns only the control of the shapes, based on image acquisition. /14

The object to be analyzed is thus a cut which has a polygonal shape and which is made in a roll of a composite sheet having a fixed width, which can have a convex, concave or complex

geometry. It is of interest to note that the internal contours (holes) are not taken into consideration.

As an example: there are four widths of ribbon made of composite material: 25 mm, 50 mm, 75 mm, 150 mm.

- The width of the ribbon is controlled by removal before installation on the ACCESS.
- The tolerance for the width is +0 -0.5 mm.
- The thickness of the carbon ribbon is 127-200 μm.
- The maximum length of a cut is 8 m. Theoretically, it is unlimited.
- The minimum length of a cut is 45 mm.
- The minimum width of carbon to be selected is 5 mm.
- The minimum distance between the front profile and the back profile is 15 mm.
- The minimum distance between two consecutive cuts is 25 mm, without removal of the waste cuttings. This distance can be greater; it varies depending on the length of the cuts. The calculation of this distance is made by the post processor.
- The minimum length of the segments parallel to the fiber is 15 mm.
- The minimum angle between two adjacent segments is 10°. If the angle is less than 10°, then the tip is truncated to 5 mm.
- The preparation of more than two segments simultaneously is not possible: there are only two blades, and the ribbon does not move backward.

The defects to be located from a mark can be classified into three categories (see Figures 3A-3D):

a) Unusual circumstance (Figures 3C and 3D):

These are accidents concerning the external geometry of the cut. This can be, for example, an excessively large undercut relief or an undercut relief which is too flared. It should be noted that the tearing off takes place in the direction of the fibers. /15

b) Variations in thickness (Figure 3B):

The variations in thickness are due to the folding of the ends of cuts, such as tips. The folding can be complete (180°) or partial (between 0° and 180°).

c) Displacements of small cuts (Figure 3A):

This type of defect occurs during the cutting of small objects, of which at least one unique segment is juxtaposed to the edge of the ribbon. The combination of translation and/or rotation can affect the initial position of the cut on the support.

It should be noted that, because the carbon ribbon is black and the paper white, there is a very clear contrast between the cuts and the rest of the ribbon which passes opposite the control block 30.

From the CAD point of view, the cuts are defined to the nearest 1/100 mm, however, taking into account the precision of the machine, one can fix a much larger tolerance threshold for the defects, for example, on the order of 1 mm.

The control of the cuts must satisfy various constraints, notably reliability, but also a real-time constraint connected with the variable advance of the cut between 0 and 30 m/min. Thus, the goal is to carry out image acquisition of the ribbon having a fixed length and to control its defects during the allotted time span, at the rate of 5 cm of ribbon to be analyzed per second, in a continuous manner. Two possibilities are available to us:

- the distance from the camera to the scene is such that one can see the ribbon portion in its entire length. One has one second for the treatments.

- the distance is less and the precision refined. The best resolution is achieved when the width of the ribbon is nearly completely included in the image. Thus, for a ribbon width of 150 mm, the resolution is less than 1 mm per pixel. In contrast, much less time is available for /16 the treatments.

Strictly, one could speak of real time, if the control of the cut and the punching of the transparent support could occur before the start of the next cut. This is impossible on the ACCESS machine, given the position of the tools and the organization of the different elements used for guidance.

The control system should be installed on the last part of the travel path of the cut, before the winding, since the guides of the ribbon can also generate deformations.

Indeed, given that this problem can not be solved, one should limit oneself to recognizing the defects of a cut only when others have already been machined (partially or completely).

Figure 4 situates the control step in a draping operation defined by its representation of the classic SADT type (SADT is the acronym for Structured Analysis and Design Technique) where the operations, as is known, are represented by rectangles which receive inputs from the left, and from which outputs leave to the right, where these operations must satisfy constraints represented above, with the help of means represented below.

The terms included in the diagram are defined as follows:

- Drape: denotes the preparation of an airfoil by applying cuts made of composite material, on a tool. It comprises the phase of preparation of the cuts, visual control, and laying of these cuts.

- Raw material spool: cassette containing the composite sheet used for the draping.

- B.E. geometry file: data originating from the design office, concerning the geometry of the cuts and the direction of the fibers.

- Machine parameters: data on the different material data, such as the material width, the /17 blades, the marking, the roller types.

- Control rules: decision rules which make it possible to classify the cuts according to quality.

- Control software: program developed to control the defects of the cuts.

- Informatics hardware: denotes the electronic hardware and informatics equipment which supports the above-mentioned software. It comprises the PC compatible computer and the graphics card.

- Draped piece: refers to the finished product, after the phases of cutting on the ACCESS machine and of laying on the ATLAS machine.

- Waste cuttings: remaining part of the composite sheet after the cutting, not used during the laying phase.

- Operator: person specializing in operating the draping machine.

- ACCESS machine: automatic machine for the preparation of the cuts, in view of a laying on a tool by the ATLAS machine.

- ATLAS machine: automatic machine which performs the laying of a piece, after it has been cut by the ACCESS machine.

- Generate DC program: denotes all the modules, from the design phase to the generation by PAOMAD of the operations carried out by the digital control.

- Cut: denotes the phase accomplished by the ACCESS machine, and which concerns the preparation of the cuts for the laying operation carried out by the ATLAS machine.

- Control: operation carried out by the vision system. The latter must produce the result "good or unsatisfactory cut."

- Laying: phase accomplished by the ATLAS machine, and which consists in applying cuts prepared by the ACCESS machine, on a tool.

- DC ACCESS program: informatics program containing the data for the piloting of the ACCESS machine.

- DC ATLAS program: informatics program containing the data for the piloting of the ATLAS machine.

- PAOMAD: software for decomposition into cuts, optimized by layers, for plane airfoils. /18
Generation of the informatics program which will pilot the digital control.

- Relaunching procedure: in the case of an unsatisfactory cut, the appearance of defects results in a repeat performance of the cutting of the composite sheet. Several manipulations have to be carried out by the specialist so that the unsatisfactory cuts are not started again.

- Quality: precision in the selection of the cuts with defects among those without defects.

- Unsatisfactory cut signal: data specifying to the operator that the cut number n comprises defects.

- Waste cuttings spool: cassette containing the wastes of raw material after the cutting of the pieces by the ACCESS machine.

The operation of control itself, to which the invention relates, is explained in Figure 5 by its representation of the SADT type, with the following additional definitions:

- Acquire the image: operation of conversion of an analog signal originating from the sensor into digital data.

- Process the image: operation intended to convert the data to be able to use it more easily in the analysis phase.

- Analyze the image: the step consists in withdrawing pertinent data from the image, for a decision.

- Correct the defects: performance by the operator of the resumption of unsatisfactory cuts.

- Advance: constraint relating to the speed of displacement of the object under the camera eye.

- Illumination: constraint concerning the conditions of visualization of the object on the scene: poses problems of reflection and regulation of the shutter opening of the camera.

- User interface: constraint imposed on the vision system to signal an error or another message to the operator. Concept of ergonomy.

These operations of image acquisition, processing, analysis or interpretation, or of correction carried out by the block schematically represented at 30, will be developed below. /19

The acquisition (Figure 6) is carried out by a video camera 31 (for example, a camera TM765 PULNIX) in combination with a CCD (Charge Coupled Device) matrix sensor with 756 x 581 photoelements, which is placed above the trajectory of the cuts before their spooling. The generated video signal meets the European CCIR standard. This video signal is transmitted to a specialized processing card 32, also called graphics card (for example, the card GIPS 25 from Electronic Informatic Application or EIA) which digitizes the signals by means of an analog-digital converter ADC bearing the reference numeral 33 (consisting of as many comparators as there are nuances of gray that one wishes to distinguish) and it forms images of the format 256 x 256 luminance points with up to 256 possible luminance levels. These images are stored in an image memory 34 which is connected to a processor 35. This card, in practice, comprises a digital-analog converter DAC bearing the reference numeral 36, for a possible visualization on the screen 37 of the processed images. The links between the components of the card 32 in practice are made on 8 bits.

A clock 38, serving to impose a rate on the reading of the pixels, is associated with the processor. This processor, in addition, generates a synchronization signal in the SCP (meaning Synchronization Camera Processor) block at the output of the camera, as well as at the output of

the graphics card. Again an offset regulation 39 is provided before the input of the graphics card, to regulate the dynamics of the signal (the gain affects the contrast and the offset modifies the luminosity). The letters B, G and R at the output of the camera 31 correspond to the blue, green and red image planes, respectively, in the case of a color camera. In the case of a black and white camera, there is only a single output.

The processing operation, which constitutes the core of the recognition process, must then allow a good reliability during the subsequent interpretation, while taking (processing + /20
interpretation) a sufficiently short duration to allow the detection of any defects in real time. Thus, one must proceed to a considerable compression of the data, since each image at the start, formed from 256 x 256 points having a luminance defined with 8 bits, represents 524.588 data bits. This compression is the result of the fact that one is only interested in the silhouette of the cuts.

A first processing step consists in binarizing the image by comparing the luminance of each point with the discrimination threshold. In that case there is only one data bit per point (luminance less than or greater than the threshold). Such a binarization is very significant, given the good contrast between the carbon cuts and their support paper. Only 256 x 256 data bits then remain.

The continuation of the treatment consists of a procedure of following contours. One starts by sweeping the image until a luminance point is found which is equal to that of the cut (minimal luminance in the case considered here, namely black cuts on white background), and then one explores the points located around this starting point in a given direction (in practice the trigonometric direction) and one selects the first one which takes on the value of the luminance of the cut. One then explores the points located around the selected point, and so on until one returns to the starting point.

This process is carried out in the entire image to follow the contours of all the separate black zones which are visible in the image.

The discrimination between various cuts or portions of cuts included in the image is made by cutting the binarized image into vertical bands, by reading the columns of pixels. There exists a constraint with regard to the distance which separates two columns of pixels. The distance between two columns must be less than the distance which separates two cuts and less than the minimum size of a cut. The reading of at least p pixels of black color indicates that the column is /21
located on a cut. If this is not the case, the column is located between two cuts. By repeating this method in the entire image, one separates the different cuts or portions of the same cut.

Rather than proceeding to a simple extraction of contours defined by pairs of coordinates for each point of the contour which is followed (numerous contour extraction filters exist for this purpose, notably the functions ROBERTS, ROBINSON, NAGAO, etc. which are present in the

library of functions of the GIPS25 card), one chooses to code these contours in such a manner that one obtains from them a representation which is adapted to the subsequent treatments, while continuing the compression of the data in the image. The choice of the coding must be sufficiently fine to allow the subsequent recognition operations, but too fine, to the point of leading to prohibitive calculation times.

The FREEMAN coding (or "chain code") is chosen, which consists in replacing the series of the points of the contour (in the plane of the image) by a series of values which gradually express the position of the points; for this purpose, it is sufficient to have, for each point, a number between 0 and 3 or 0 and 7, depending on whether one explores 4 or 8 points around each point.

For example, the curve of Figure 7, using the coding defined in Figure 8, is defined simply by 0200107605444, etc.

This classic FREEMAN function is also available on the GIPS25 card.

In a variant, this FREEMAN coding (derived coding) gives a succession of numbers characterizing the difference in orientation between successive elementary segments, which gives data which are theoretically invariant after rotation; however, some artifacts are connected with this discretization.

One then carries out the polygonal approximation of the contour considered, using the recursive method known by the name of "cord method." /22

In a simplified description, it consists in choosing a priori two points A and B of the curve to be approximated; if all the points of the curve between A and B are at a distance from the cord AB which is less than a preestablished threshold value, this cord is then validated, otherwise one identifies the point P of the curve which is farthest from the cord AB and one iterates the process with the pair of points AP then PB, and so on. To determine the points A and B at the time of the startup, one determines the rectangle which circumscribes a cut. The points A and B are always located in contour portions which are contiguous to the small sides of the rectangle. If the small sides of the rectangle are in a horizontal position, the point A is then the point of the contour of the cut which is located the farthest to the right on a small side; the point B of the point of the contour of the cut which is located the farthest on the right is on the other small side. If the small sides of the rectangle are in a vertical position, the point A is then the point of the contour of the cut which is located in the highest position on the small side; the point B is the point of the contour of the cut which is located in the lowest position on the other small side. The regulation of the threshold is of great importance, because it directly influences the number of segments. This threshold value is chosen, for example, so that one has a total number of segments in the contour which is less than or equal to 128.

From the coordinates of the apexes of the polygon which have been identified by the polygonal approximation, one carries out a vectorization phase which consists in calculating the length of each side or segment of the polygon, as well as the angle formed between two successive segments (from the lengths of these segments, and from the scalar product and the vector product of the vectors which constitutes these segments).

Advantageously, one finally proceeds to a cleaning operation which is intended to eliminate any unwanted apexes: for this purpose one defines an angular threshold, and one /23
eliminates any apex located between two segments which are in the extension of each other with an angular shift which is less than this threshold. For example, this threshold is chosen to be equal to 10°.

Various tests have shown that, in practice, the average number of sides identified in the contours of cuts by the manufacture of parts of planes is on the order of 10. Given that it takes approximately 4 octets to characterize each apex compared to the preceding one, it is thus sufficient to use approximately 40 octets to characterize a cut. Naturally, this number is greater if the field of the image contains or intercepts several cuts or portions of a cut (indeed, the smaller the cuts are, the fewer segments there are on average). In any case, the number of data octets which are useful for the interpretation is much lower than the 256 x 256 data octets of the raw image. It is this compensation which allows one to proceed in real time (with an advance speed of 30 m/min, that is 50 cm/s, therefore one must be capable of analyzing one 50-cm long window every second).

The interpretation of the data which have been processed in this manner is made by a comparison with the theoretical data defined by PAOMAD for each cut, from which one derives, beforehand (very small modifications of PAOMAD are sufficient for this purpose) the polygonal approximations (it is even routine practice for the theoretical cuts to have a polygonal shape) and the associated vector coordinates.

To carry out these comparisons, one identifies, by counting, the cuts which advance in front of the block 30 in such a manner that one can determine which theoretical cuts one should compare them with.

For this purpose, another camera 40 is available which delivers a video signal to a card 41 of the SUPERCAM type. SUPERCAM is a GIPS 25 image processing card from EIA, which is integrated in an industrial casing. The mode of operation of SUPERCAM is very simple: it is based on the remote loading of applications from the microcomputer, which are then /24
executed in complete autonomy. The commands of remote loading, execution and stoppage are independent of each other and can thus be sent anywhere in the program of the application. The camera connected to SUPERCAM (for counting the cuts) and the camera connected to the microcomputer (for the analysis of the defects) are calibrated in such a manner that the same

image is integrated in the two sensors. The counting of the cuts by SUPERCAM (a counting program has been remote loaded) is carried out by reading and analysis of the two columns of pixels 50 on the image, to simulate a mechanical hysteresis. It is the passage of cuts at the place where the reading of the columns 50 in the image field is carried out which increases the count value.

The distance between the two lines is less than the separation between two consecutive cuts, but sufficient so that the regressive movement of the ribbon (mentioned in reference to Figure 2) does not disturb the counting.

Thus, the SUPERCAM knows at all times the number of the cut which is close to the edge which is the farthest on the right in Figure 9. A parallel link is provided for the transfer of this datum to the image processing system. One also already knows the number of cuts or portions of a cut in the image, and one can thus access the theoretical data corresponding to these different cuts or portions of a cut.

The underlying idea of the comparison is derived from the prior decomposition of the entire image into several subsets where each contains only a single cut or a portion of a cut (see above and Figure 10), and in then looking for the series of angles which are measured in the theoretical series which defines the cut. It is unnecessary to take into account the distance data because, as already specified, the purpose is not to conduct a dimensional control. In addition, the angles are invariant with respect to rotation.

In the case of Figure 11, where the cut is entirely contained in the image, all the measured angles $\alpha 1$-$\alpha 9$ are used for the comparison. On the other hand, in the case of Figure 12, where two of the angles correspond to the intercept of the image with the cut, only the angles $\alpha 1$-$\alpha 7$ are taken into account. /25

The comparison algorithm is presented in Figure 13.

A brief review of language theory will be useful.

Definitions

- Let A be an alphabet, the elements of A are letters (here angles),
- a word is defined as a finite series of letters, noted f,
- the length of a word f is the length of the series. It is noted $|f|$,
- if f is a word of length n then f is an application of $\{1,n\} \rightarrow A$

$f = f(1)f(2)f(3)\ldots f(n)$

Internal operation: A^* = set of words written using the alphabet A

Properties

- Associative concatenation:

(f o g) o h = f o (g o h) = f o g o h

ε empty word

ϕ empty set

Remark

$|f.g| = |f| + |g|$

$|\varepsilon| = 0$

Definition of the factor

h is a factor of $f \Leftrightarrow \{ \exists\ u,\ v \in A^*\ tq\ f = u\ h\ v \}$

h is a left factor of $f \Leftrightarrow \{ \exists\ \ v \in A^*\ tq\ f = h\ v \}$

h is a right factor of $f \Leftrightarrow \{ \exists\ u \in A^*\ tq\ f = u\ h \}$

Lévi's lemma

If $f.g = u.v$ tq $f,\ g,\ u,\ v,\ \in A^*$

then:

1. If $|f| > |u|$ then $f = u \cdot h$ and $v = h \cdot g$
2. If $|f| = |u|$ then $f = u$ and $g = v$ /26
3. If $|f| < |u|$ then $u = f \cdot h$ and $g = h \cdot v$

In addition, if $f \in A^*$, one defines:

ϕ (f) = {set of the distinct left and right factors}

= {s tq g left factor of f and g right factor of f strict}

φ (f) is the largest word of ϕ(f)

First property:

$$\phi(f) = \{\varphi(f) \cup \phi(\varphi(f))\}$$

Second property:

$$\phi(f) > \phi(\varphi(f) > \phi(\varphi^k(f) > \phi$$

Third property:

$\varphi(f),\ \varphi^2(f),\ \ldots\ldots,\ \varphi^k(f),$ ε predetermined order

$$\cup^k\ \varphi^k(f) = \phi(f)$$

Fourth property:

$$w \in \phi(f) \Leftrightarrow \exists\ k\ \text{tq}\ w = \varphi^k(f)$$

Based on these definitions, one poses the following problem:

How to calculate $\varphi(f \cdot a)$? $f \in A^*$ and $\in A$

For this purpose, several forms of expression of the solution are possible:

First form:

$\varphi(f.a) = \{u.a$ or u is the largest word of $\phi(f)$ tq u.a is a left factor of f, otherwise $\varepsilon\}$

Second form:

$\varphi(f.a) = \{$ 1/ u.a tq $u \in \phi(f)$

2/ the letter in position $|u|+1$ is an a

3/ it is the largest one verifying 1/ and 2/,

otherwise $\varepsilon\}$

Third form:

$\varphi(f.a) = \{\varphi^k(f).a$ where k is the smallest whole number tq the letter in position $|\varphi^k(f)|+1$ or an a, otherwise $\varepsilon\}$

Notations:

Let there be a function Y: $[1, n] \to [0, n-1]$

Let $f = a_1a_2a_3\ldots a_n$

$f \to i$

$\varphi \downarrow \quad \downarrow \Psi$

$\varphi(f) \to j$

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$$\Psi(i) = j \Longleftrightarrow \varphi(a_1a_2a_3\ldots a_i) = a_1a_2a_3\ldots a_j$$

Example based on letters: This can be interpreted as the search for a chain, which is simultaneously a left factor and a right factor of a word.

	1	2	3	4	5	6	7	8	9	10
	a	b	c	a	b	c	a	c	a	b
Ψ	0	0	0	1	2	3	4	0	1	2

$\Psi(1) = 0$

$\Psi(i+1) = \Psi^k(i)+1$

where k is the smallest whole number

tq $a_{\Psi^k(i)+1} = a_{i+1}$ otherwise 0.

In this case, the complexity is of O(N). More precisely, the search for a word m in f corresponds to evaluating Ψ(m # f). Here # is a letter which one cannot encounter. Given that in the present application, the letters correspond to angle values, the letter # takes on the value 500, since the angle α, $\alpha \in [0,360]$. The complexity then is O(|m|+|f|).

The distance used is the square of the Euclidian distance: $d(a_i, a_j) = (a_j - a_j)^2$.

In other words, this algorithm consists in searching for a series of angle values α_1 α_2 α_3... p which are supplied by imaging in the series of angles β_1 β_2...β_q which [gives] the theoretical cut by evaluation of the function Ψ (α_1 α_2 α_3 ... α_p 500 β_1 β_2...β_q).

We write $|\alpha_1 \alpha_2 \alpha_3 \ldots \alpha_p| = P$ and

$|\beta_1 \beta_2 \ldots \beta_q| = q$

If the separation between Ψ(i) (for i ranging from 1) p+q+1) [sic: 1 to (p+q+1)]) and p is less than a threshold, one then considers that the series of angles supplied by imaging has been found in the series of angles of the theoretical cut, and the cut is validated as being correct.

On the other hand, if the separation between Ψ(i) and p is greater than a threshold, an alarm signal is triggered, because the cut is considered incorrect. /28

It is preferred to use, simultaneously with the control strategy employing the vectorization of the polygonal contours, and then the comparison of the measured angles with the theoretical angles, a control strategy with neuronal networks. This technique, as is known, consists in simulating on a computer the connections between the biological nerve cells (reference is notably made to DAVALO, E., NAIM, P., Des réseaux de neurones [On Neuronal networks], EYROLLES PARIS, 189, or to LE CUN Yann., Modèle connexionniste de l'apprentissage [Connectionist model of learning, PhD, Informatics and System, 1987, University Paris VI).

The special feature of artificial neuronal networks is their ability of learning by means of the representative elements of the different classes of elements to be discriminated. Later, an unknown element can be classified in one of these classes, provided that it was possible to cause the network to converge during the learning.

A brief review is presented below.

Figure 14 is a schematic representation of a formal (or artificial) neuron, while Figure 15 is a schematic representation of a neuronal network with several layers.

A formal neuron is defined by:

- the nature of its inputs e_i with i varying from 1 to n,
- the total input function h,
- the activation function f,
- the output function g, and
- the unique or multiple nature of the outputs.

To each input, a weighting parameter, or weight, is applied, which characterizes the links between neurons.

The total input E is defined by h ($e_1, \ldots e_n$); the state of the neuron is given by A = f (E) and the output of a neuron is given by S = g(A).

The network (Figure 15) is organized in successive layers, where each neuron of a layer is connected to the neurons of the next layer, without connection between neurons of the same layer. /29

The principle of the algorithm is based on the fact that, because one can propagate the signal from the input layer to the output layer, one can back propagate the error which has been committed following the reverse path.

Let there be a linear neuron with threshold, comprising n input cells and one output cell, as in Figure 16. The output value is assumed to be +1, if the weighted sum is positive, and -1 otherwise.

The following notation is used:

- E is the set of the examples to be classified
- E^h is a particular example
- E_j^h is the jth component of the example E^h
- W_j is the weighting parameter of the jth input cell
- W_O is the threshold of the decision neuron
- O^h is the response supplied by the neuron, for example, h
- T^h is the desired response for the example h

The WIDROW-HOFF learning rule stipulates that the error signal is equal to the difference between the weighted sum of the inputs without threshold and the expected result. Thus, this method requires a modification of the weights, as long as the weighted sum of the inputs of the neuron is not equal to +1 or -1, even if the response with threshold is correct. The difference is: $\Delta^h = T^h - \Sigma_j W_j E_j^h$

One modifies each weight W_j by $\Delta W_j = k \cdot \Delta^h \cdot E_j^h$

In the general case of Figure 17, the learning during the back propagation is identical to the WIDROW-HOFF rule. One then combines the data of the example with the desired result. For each example presented to the network, an output is calculated, by forward propagation (from the input layer toward the output layer). One can then calculate the error between the actual output and the desired output. It is the square sum of the errors on the output /30
cell: error = $\Sigma_h (\Delta^h)^2$

The error which one seeks to minimize is a function of the weights. It is then back propagated in the network, to modify each weight. This is repeated for all the examples, and if the error is less than a preestablished threshold, one considers the network to have converged.

If one expresses these statements in a formal manner:

let X $(x_1 \ldots, x_n)$ be an element with n inputs

let Y $(y_1 \ldots Y_m)$ be an element with m desired outputs

let S $(s_1 \ldots, s_m)$ be an element with m actual outputs

then $E(W) = \Sigma^m_{i=1}(y_i-s_i)^2$

The rule of modification of the weights for the Example X presented the kth time is:

$W_{ij}(k) = W_{ij}(k-1) - e(k) \cdot d_i \cdot O_j$

where d_i is calculated gradually from the output layer toward the input layer.

a – for the output layer: $d_i = 2 \cdot (s_i-y_i) \cdot f(I_i)$

b – for the internal layers: $d_i = \Sigma_h d_h \cdot W_{hi} f(I_i)$

with h going through the neurons toward which the neuron i sends a connection

f is the sigmoid function

O_j denotes the output of the neuron j

I_i denotes the input of the neuron i $I_i = \Sigma_j W_{ij} O_j$

e(k) denotes the slope of the gradient.

The back propagation algorithm used according to the invention was based on the following choices.

As far as the input data for the network are concerned, they are obviously derived from the data supplied by the polygonal approximation. Rather than choosing the lengths of segments and/or the angles, or the curvilinear abscissa, it was decided to determine the curvilinear abscissa from the coordinates, and to convert it to the frequency domain. Indeed, a discrete FOURIER transform process allows one to obtain a series of coefficients which are calculated by the following formula:

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$$F(u) = \frac{1}{N} \sum_{x=0}^{N-1} f(x)\, e^{\frac{-2jmux}{N}}$$

for u = 0, 1,...,N
where j = $\sqrt{-1}$ and u denotes the frequency.

The fact of converting to the frequency domain presents two advantages:

- the dimension of the types of defects being relatively small, compared to the dimensions of the cut, one can assume that a discrimination on the high frequencies will make it possible to detect the defects,

- using a preestablished number of coefficients of the FOURIER transform, one imposes a size with regard to the number of data presented at the inputs of the network. In the case of this application, one decides to keep only the first 10 coefficients of the FOURIER transform, or 10 inputs for the neuronal network.

One chooses a linear function as total input function:

$$h(e_1, \ldots e_n) = \Sigma^n{}_{i=1} W_i e_i$$

one chooses for the activation function, a function of the sigmoid type:

$$f(x) = a \frac{(e^{kx}-1)}{e^{kx}+1}$$

Finally, for the output function, one chooses the identity function.

After numerous attempts of achieving convergence of the network, the following structure was adopted:

- an input layer (comprising 10 elements)
- a hidden layer (number of elements less than 10) and
- an output layer with one element.

Tests were carried out with an interpretation, after polygonal approximation, of the first above-mentioned type, that is with vectorization and comparison to the theoretical data of the cuts.

The tests were repeated by analyzing the same scene n times, for slightly offset /32
positions. The total time was then measured, and then divided by n to derive therefrom the analysis time of one image. The first manipulation consisted in determining n, to prevent continued influence of the PC clock, whose cue duration is on the order of 55 ms. This was intuitively approached when the analysis time of an image no longer varied starting at a given n.

In our case, it seemed that 100 was a value which respected this constraint. In all the remaining text, this value constitutes the number of treatment loops.

The images which were analyzed in the context of this part all had the same dimensions:

- 270 mm for the x axis and
- 160 mm for the y axis.

The tested cuts are represented in Figures 18-1 to 18-18; they are without defect. The results are reported in Table 1.

The first conclusion one can draw therefrom is the total ineffectiveness of the algorithm in processing the cuts with curves. The cause for this failure is the polygonal approximation, because the number of found segments is different from that of the theoretical cut, a result which then always implies detection of a defect. Taking this lacuna into consideration, the false alarm rate is 12.5%. In contrast, if one only considers the cuts with curves, the rate decreases to 1.36%. In that case, the system thus turns out to be very effective.

The second conclusion concerns the execution times: the average time of rapidity of analysis is 0.47 sec. If one excludes the cases where a defect was encountered, the rapidity is equal to 0.43 sec.

However, for a 270*160 image, the required analysis time (with the constraint of a maximum speed of 30 m/min) is 0.54 sec. Thus, one can conclude therefrom that this constraint of the specifications is respected, and that one can reduce the inspection field even further, to increase the precision. Indeed, the constraint of a maximum speed is penalizing, because it /33
occurs essentially with very long rectangular cuts. However, experience has proven that these cuts never have defects.

Similar tests were carried out on cuts which now comprise defects (see Figures 19-1 to 19-9). The measurements took place for defect sizes of 3 mm and 4 mm to show the sensitivity of the method.

The results are reported in Table 2.

Based on the above, on can conclude on the influence of the size of the defect on the performances of the recognition system: from a success rate of 51.33% in the case of a size of 3 mm, one goes to a rate of 99.66% in the case of a size of 4 mm. The conclusion one can draw therefrom is that the interpretation algorithm performs well from the time on when the size of the defect is sufficiently large (>3 mm).

The failure to detect defects of small size is due to the polygonal approximation. Indeed, the precision of this algorithm is due to the value of the regulation parameter. However, the latter cannot exceed a minimum value, without which a number of resulting points is too high. This number of points is fixed at 64 per half contour.

Moreover, the procedure for controlling by neuronal networks has been tested by means of a neuronal network simulation software known by the name RENARD (REseau de Neurones A Rétropropagation D'erreur [Neuronal Network with Back Propagation of Error]) developed by AEROSPATIALE.

A learning process carried out on 400 cuts made it possible to obtain a success rate of 85% on a test set of 50 cuts. This rate can be improved, if the pertinence of the example is strengthened.

One can note that the control of recognition, in the case of theoretically polygonal cuts (without curve):

- the false alarm rate for cuts without defects was 13.6%, /34

- the rate of correct detection of defects larger than 3 mm was 99.66%,

- the average analysis time for 270 mm x 160 mm images was 0.43 sec (approximately 20 msec for acquisition and 400 msec for processing/interpretation), which is compatible with control in real time. And, it is less than the theoretical analysis time which was evaluated at 0.54 sec taking into account the maximum advance rate of 30 m/min. However, it was shown that this maximum speed constraint is penalizing, because in practice it only occurs in the case of very long rectangular cuts, however, experience has shown that this type of cut never has any defects. Thus, if necessary, the precision should be improved with regard to the size of the detectable defects, because, in practice, these defects only appear in cuts for which the advance speeds are less than the above-mentioned maximum.

When the cuts comprise curves, it is preferred to use a hybrid method which simultaneously uses comparison with the CAD data and classification by neuronal networks.

This is represented in Figure 20.

A decision rule of the type "the cut is validated without defect if the number of segments of a cut by image processing is much lower than the number of segments of the theoretical cut and if the result obtained by the neuronal network is good" allows a satisfactory synthesis. Other decision rules can be:

- if the number of consecutive angles identical to the theoretical cut is greater than a predetermined threshold, and if the result obtained by a neuronal network is good, the cut is validated as correct.

Thus, the invention indeed allows the control of the cuts made by a machine, such as ACCESS.

It also allows a control of the conformity of the geometry of planar pieces. /35

Naturally, the preceding description was only proposed as a nonlimiting example and numerous variants can be proposed by the person skilled in the art without leaving the scope of the invention.

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Table 1

1 numéro de l'image	2 rapidité en s	3 taux de fausse alarme sur 100
1	0,32	0
2	0,4	1
3	0,42	0
4	0,43	4
5	0,4	0
6	0,48	0
7	0,48	0
8	0,53	0
9	0,52	1
10	0,64	11
11	0,45	6
12	0,4	0
13	0,46	0
14	0,44	0
15	0,36	1
16	0,42	1
17	0,65	100
18	0,63	100

Key: 1 Number of the image
2 Rapidity in sec
3 False alarm rate out of 100

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Table 2

1 numéro de l'image	2 taille du défaut en mm	3 taux de détection
1	3	17
	4	97
2	3	35
	4	100
3	3	55
	4	100
4	3	63
	4	100
5	3	35
	4	100
6	3	77
	4	100
7	3	50
	4	100
8	3	100
	4	100
9	3	30
	4	100

Key: 1 Number of the image
2 Size of the defect in mm
3 Detection rate

Claims /38

1. Method for controlling successive cuts which are at least approximately polygonal made by a machine for cutting a ribbon (2,13,15) from the data on successive theoretical cuts, according to which:

- one advances the cuts over a contrasted background,
- one acquires a succession of images of a field encompassing the entire width of the ribbon, at a frequency such that two successive images encompass the zones of advancing ribbons which partially overlap,
- one binarizes the image by associating with each point one of the two values, depending on whether the luminance of the point is greater or less than the threshold,
- one applies an extraction of contour by Freeman coding to this binarized image,
- one identifies each contour,
- one divides the image into as many processing windows as there are closed or unclosed contours,
- one produces a polygonal approximation of each closed or unclosed contour,
- one vectorizes each segment of the polygonal approximation by determining at least one angle between two successive segments,
- one compares the succession of the angles measured in the polygonal approximation to the succession of angles of a polygonal approximation of the theoretical cut having the same identification,
- one detects a defect if one does not find the succession of angles measured in the succession of the angles of the polygonal approximation of the theoretical cut having the same identification.

2. Method according to Claim 1, characterized in that, in addition:

- one constructs a network of neurons with n inputs, three layers and one output is constructed,
- one causes this neuronal network to undergo learning, using a set of defect-free cuts, /39 and a set of cuts with defects, where each cut is characterized, with polygonal approximation, with N magnitudes applied with N inputs,
- simultaneously with the steps of vectorization and comparison, one applies N magnitudes of each polygonal approximation to this network of neurons,
- and one detects a defect if a predetermined decision rule is satisfied, which combines the results of the comparison operation and the output of the neuronal network.

3. Method according to Claim 2, characterized in that the N magnitudes which characterize each approximation are N values taken on by the discrete Fourier function applied to the curvilinear abscissa for frequencies from 1 to N.

4. Method according to Claim 3, characterized in that N is 10.

5. Method according to any one of Claims 2-4, characterized in that the input function of each neuron is a linear function of the weighted entries, the activation function is of the sigmoid type and the output function is an identify function.

6. Method according to any one of Claims 2-5, characterized in that the cuts without defects which are used for learning are curved sections.

7. Method according to any one of Claims 2-6, characterized in that one of the rules of decision is: "the cut is validated without defect if the number of segments of a cut by image processing is very much lower than the number of segments of the theoretical cut and the result obtained by a neuronal network is good."

8. Method according to any one of Claims 1-7, characterized in that one identifies each contour by counting cuts which pass through the field of the camera.

9. Method according to any one of Claims 1-9, characterized in that the speed of advance of the ribbon being at most 30 m/min, the time of acquisition for binarization, contour extraction, polygonal approximation and comparison is less than 0.5 sec.

10. Method according to any one of Claims 1-9, characterized in that the cuts are made in a composite of carbon fibers which are unidirectional and applied to a white support.

11. Method according to any one of Claims 1-10, characterized in that after vectorization, and before comparison, one proceeds to replacing by a unique vector any pair of successive vectors whose angular separation is less than a predetermined threshold.

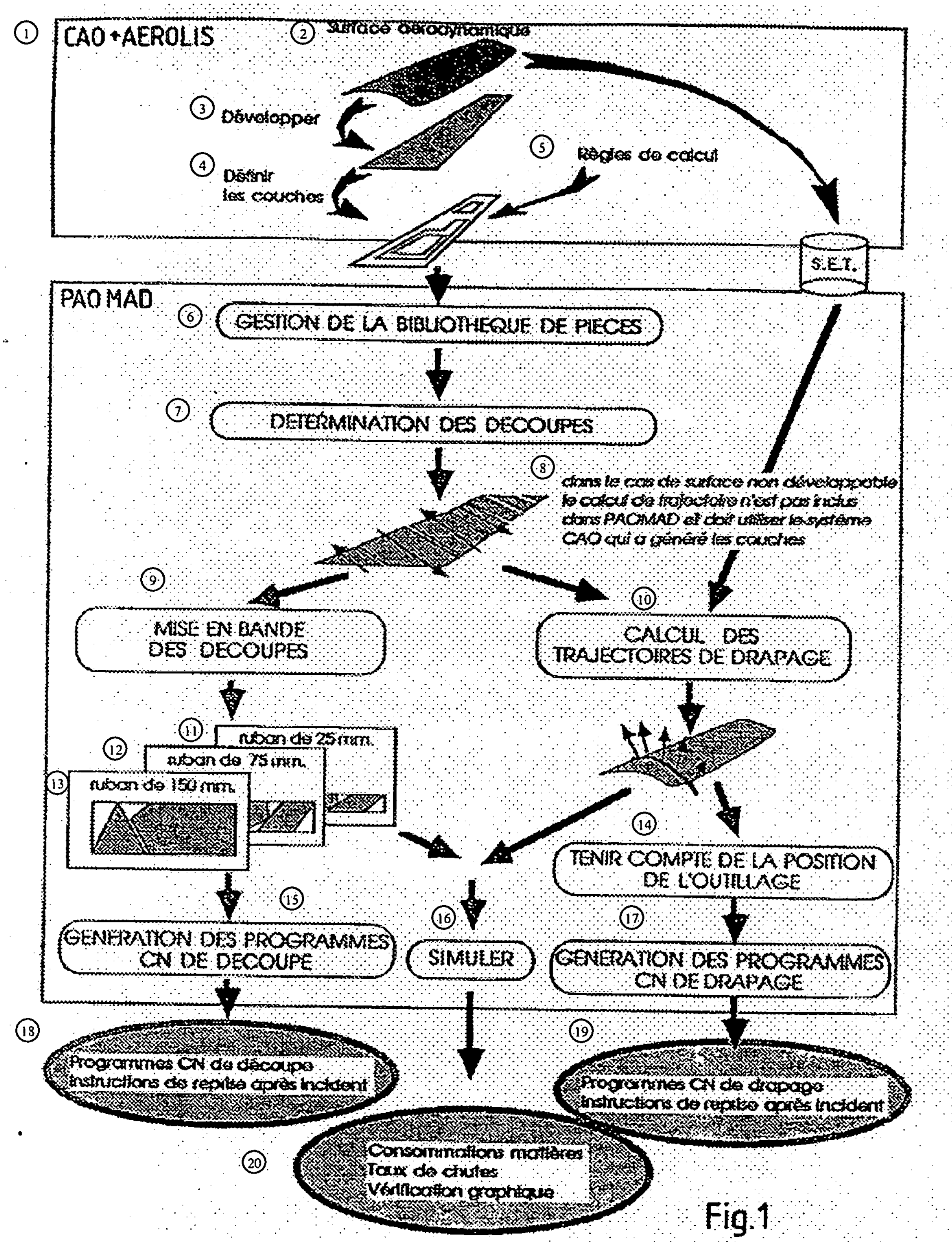

CAO+AEROLIS
Surface aérodynamique
Développer
Définir
les couches
Règles de calcul
S.E.T.
PAO MAD
GESTION DE LA BIBLIOTHEQUE DE PIECES
DETERMINATION DES DECOUPES
dans le cas de surface non développable
le calcul de trajectoire n'est pas inclus
dans PAOMAD et doit utiliser le système
CAO qui a généré les couches
MISE EN BANDE
DES DECOUPES
CALCUL DES
TRAJECTOIRES DE DRAPAGE
ruban de 25 mm.
ruban de 75 mm.
ruban de 150 mm.
TENIR COMPTE DE LA POSITION
DE L'OUTILLAGE
GENERATION DES PROGRAMMES
CN DE DECOUPE
SIMULER
GENERATION DES PROGRAMMES
CN DE DRAPAGE
Programmes CN de découpe
Instructions de reprise après incident
Programmes CN de drapage
Instructions de reprise après incident
Consommations matières
Taux de chutes
Vérification graphique

Fig.1

Key:

Key:	1	CAD + AEROLIS
	2	Aerodynamic surface
	3	Develop
	4	Calculation rules
	5	Define the layers
	6	Management of the library of pieces
	7	Determination of the cuts
	8	In the case of a surface which cannot be developed, the calculation of the trajectory is not included in PAOMAD and it must use the CAD system which generated the layers
	9	Separation of the cuts into bands
	10	Calculation of the draping trajectories
	11	25-mm ribbon
	12	75 mm ribbon
	13	150-mm ribbon
	14	Take into account the position of the tool
	15	Generation of DC cutting programs
	16	Simulate
	17	Generation of the DC draping programs
	18	DC cutting programs Instructions for resumption after incident
	19	DC draping programs Instructions for resumption after incident
	20	Consumption of materials Rate of wastes Graphic verification

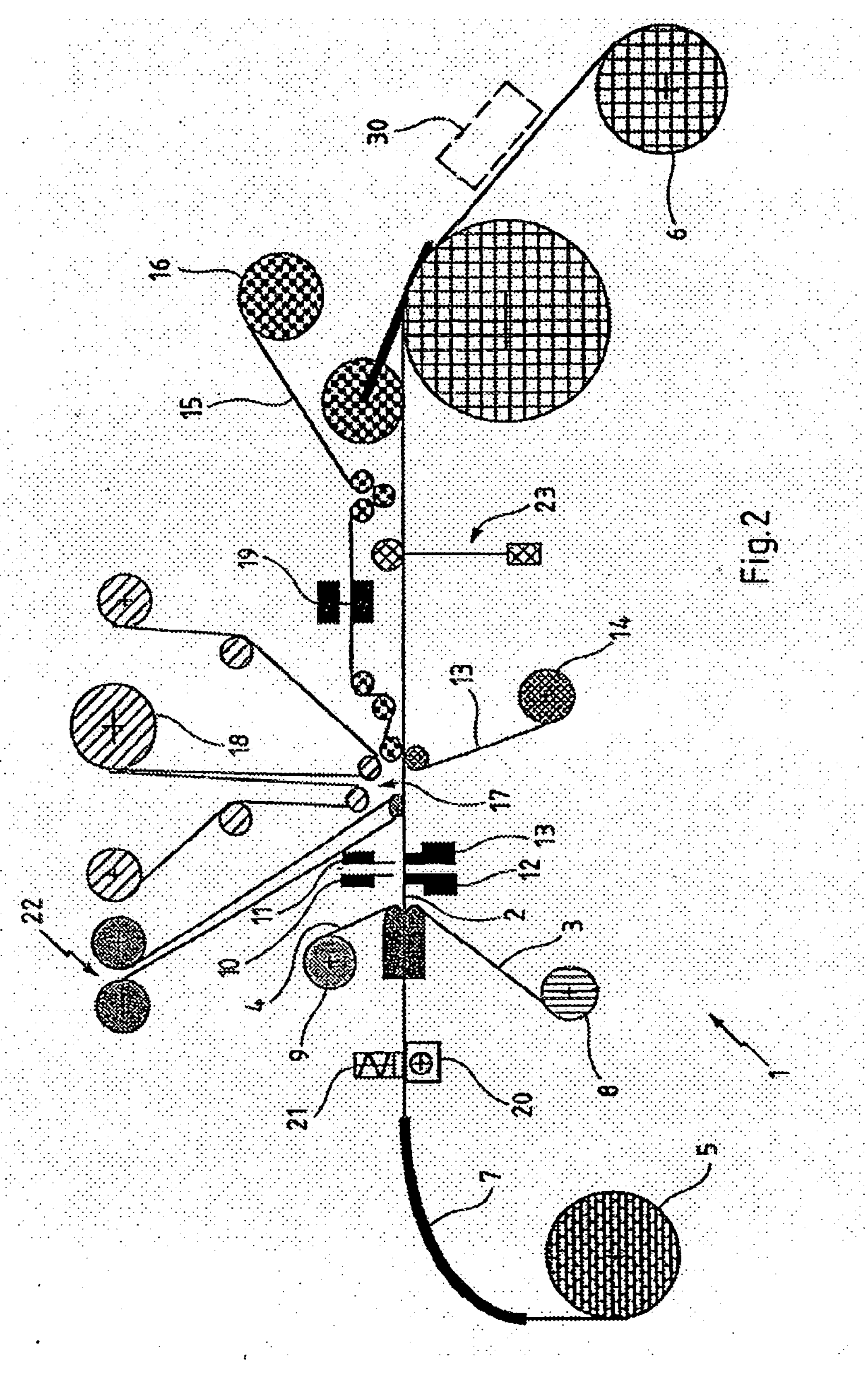


Fig.2

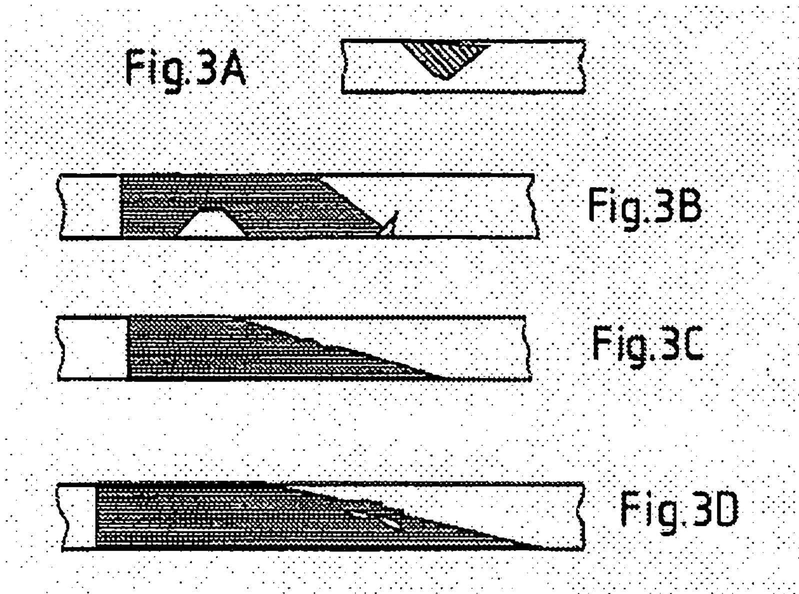


Fig.3A

Fig.3B

Fig.3C

Fig.3D

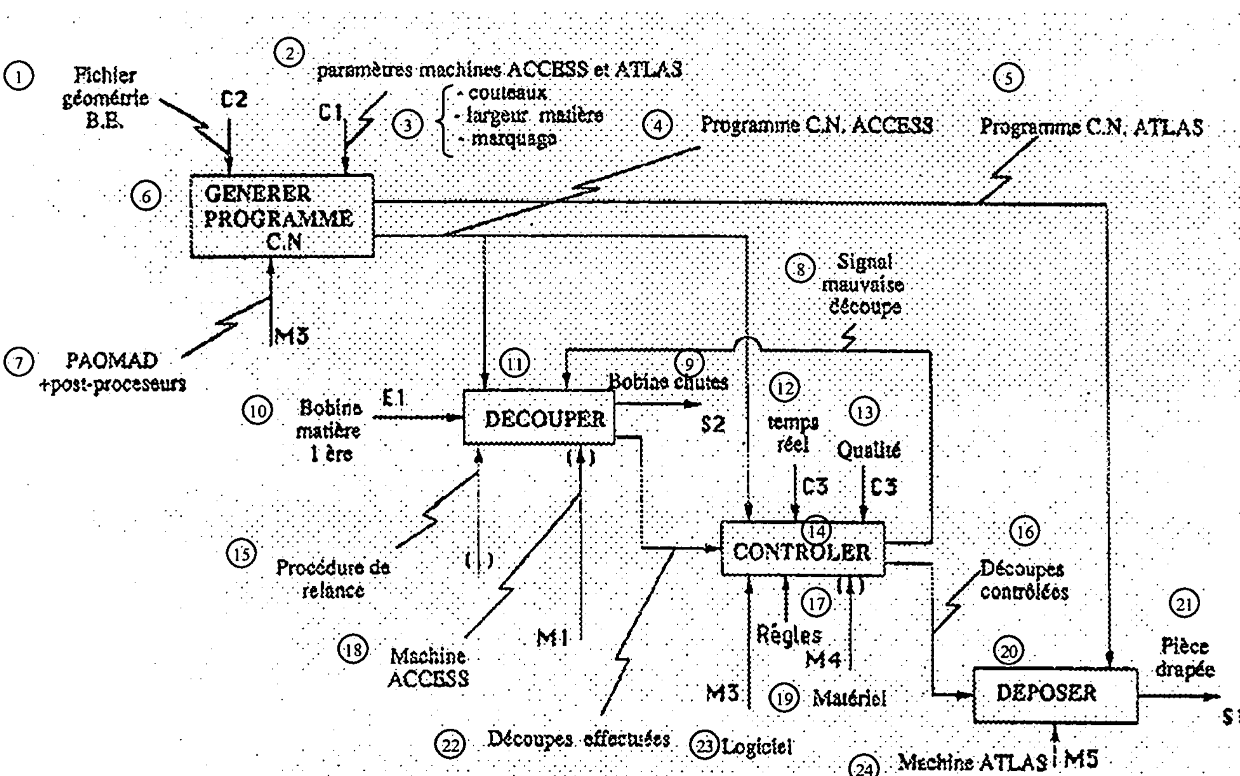
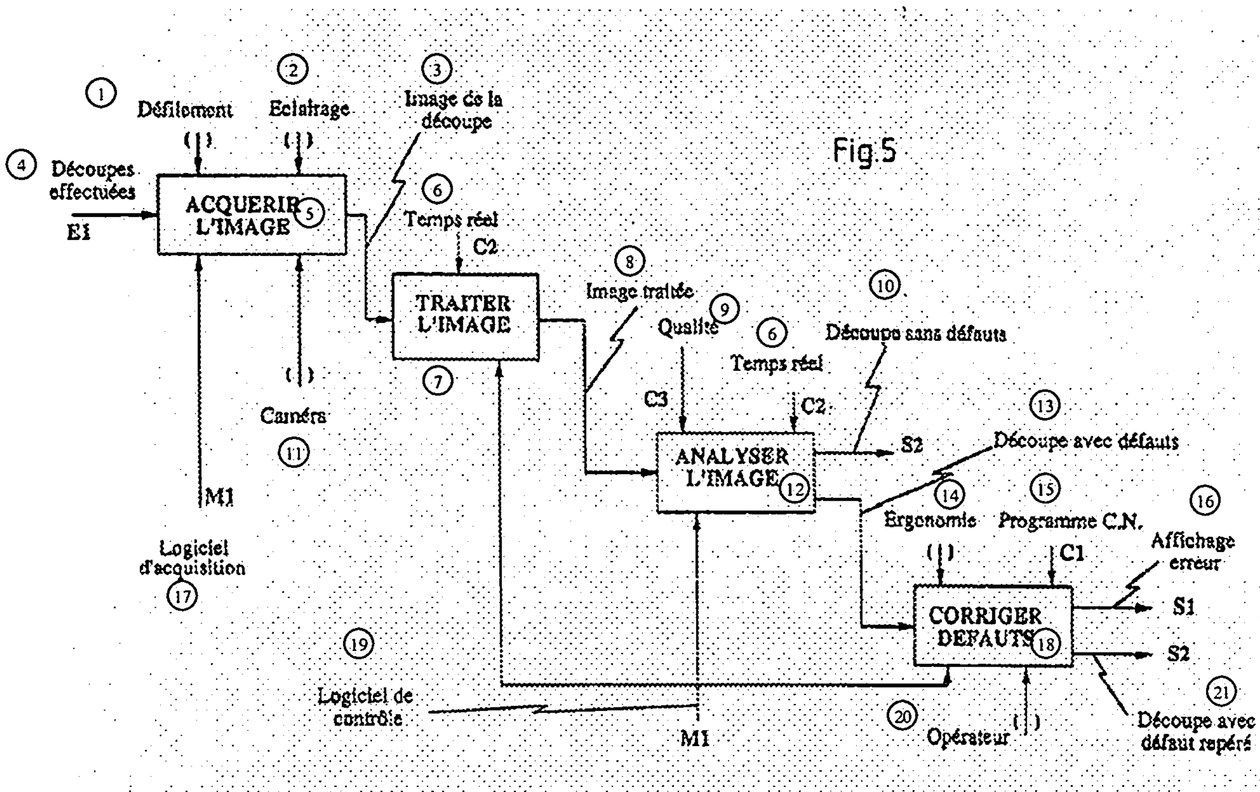


Fig.4

Key: 1 B.E. geometry file
2 ACCESS and ATLAS machine parameters

3	- Blades
	- Material width
	- Marking
4	DC ACCESS program
5	DC ATLAS program
6	Generate DC program
7	PAOMAD + post processors
8	Signal unsatisfactory cut
9	Waste cuttings spool
10	Raw material spool
11	Cut
12	Real time
13	Quality
14	Control
15	Relaunching procedure
16	Controlled cuts
17	Rules
18	ACCESS machine
19	Material
20	Laying
21	Draped piece
22	Cuts made
23	Software
24	ATLAS machine



Key:

Key:	1	Advance
	2	Illumination
	3	Image of the cut
	4	Cuts made
	5	Acquire the image
	6	Real time
	7	Process the image
	8	Processed image
	9	Quality
	10	Cut without defects
	11	Camera
	12	Analyze the image
	13	Cut with defects
	14	Ergonomy
	15	DC program
	16	Error display
	17	Acquisition software
	18	Correct defects
	19	Control software
	20	Operator
	21	Cut with marked defect

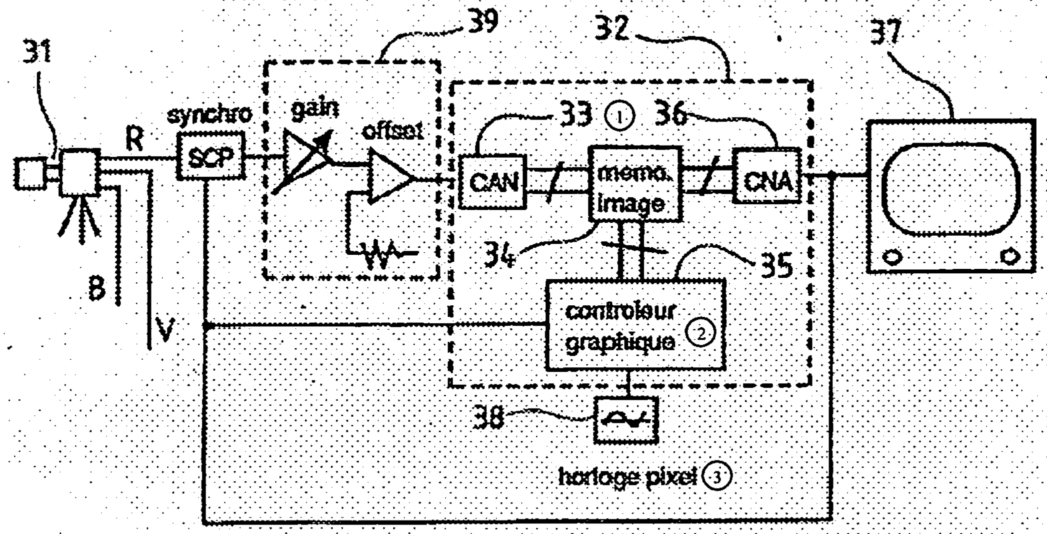


Fig.6

Key: 1 Store image in memory
2 Graphic controller
3 Pixel clock

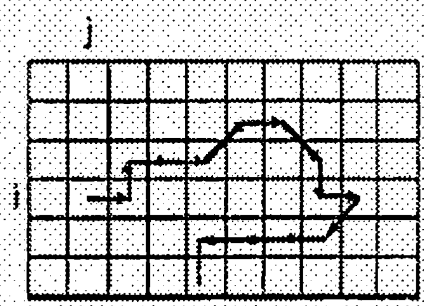


Fig.7

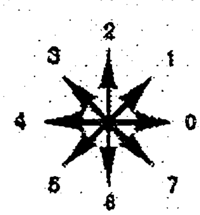


Fig.8

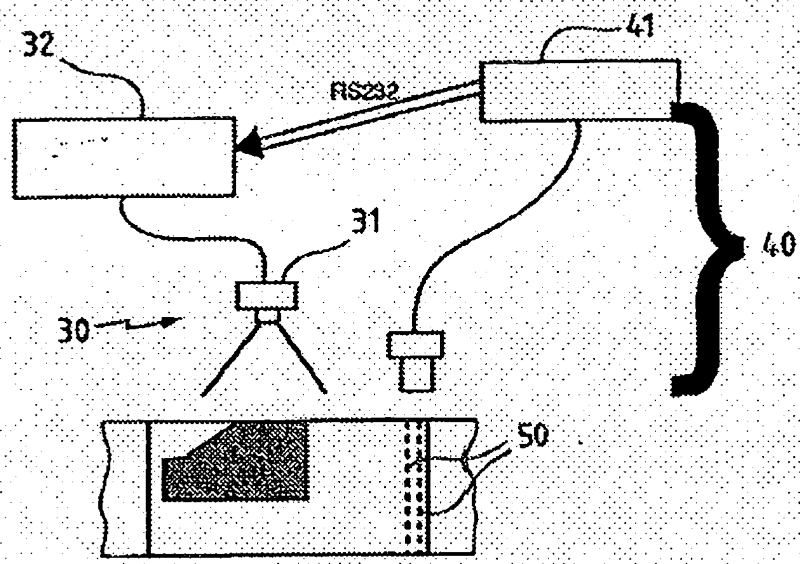


Fig.9

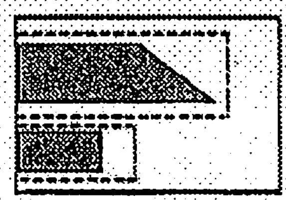


Fig.10

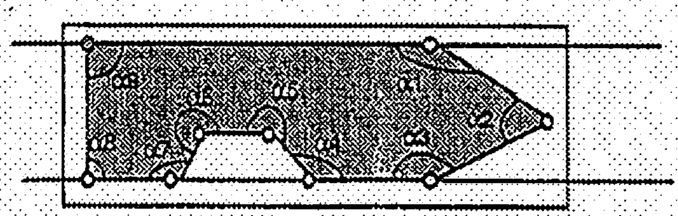


Fig.11

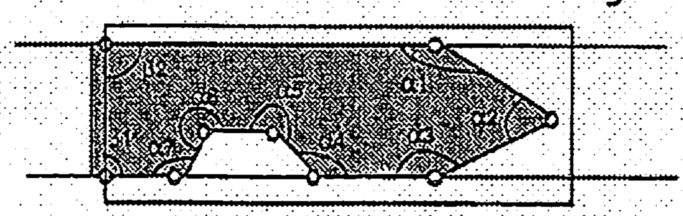


Fig.12

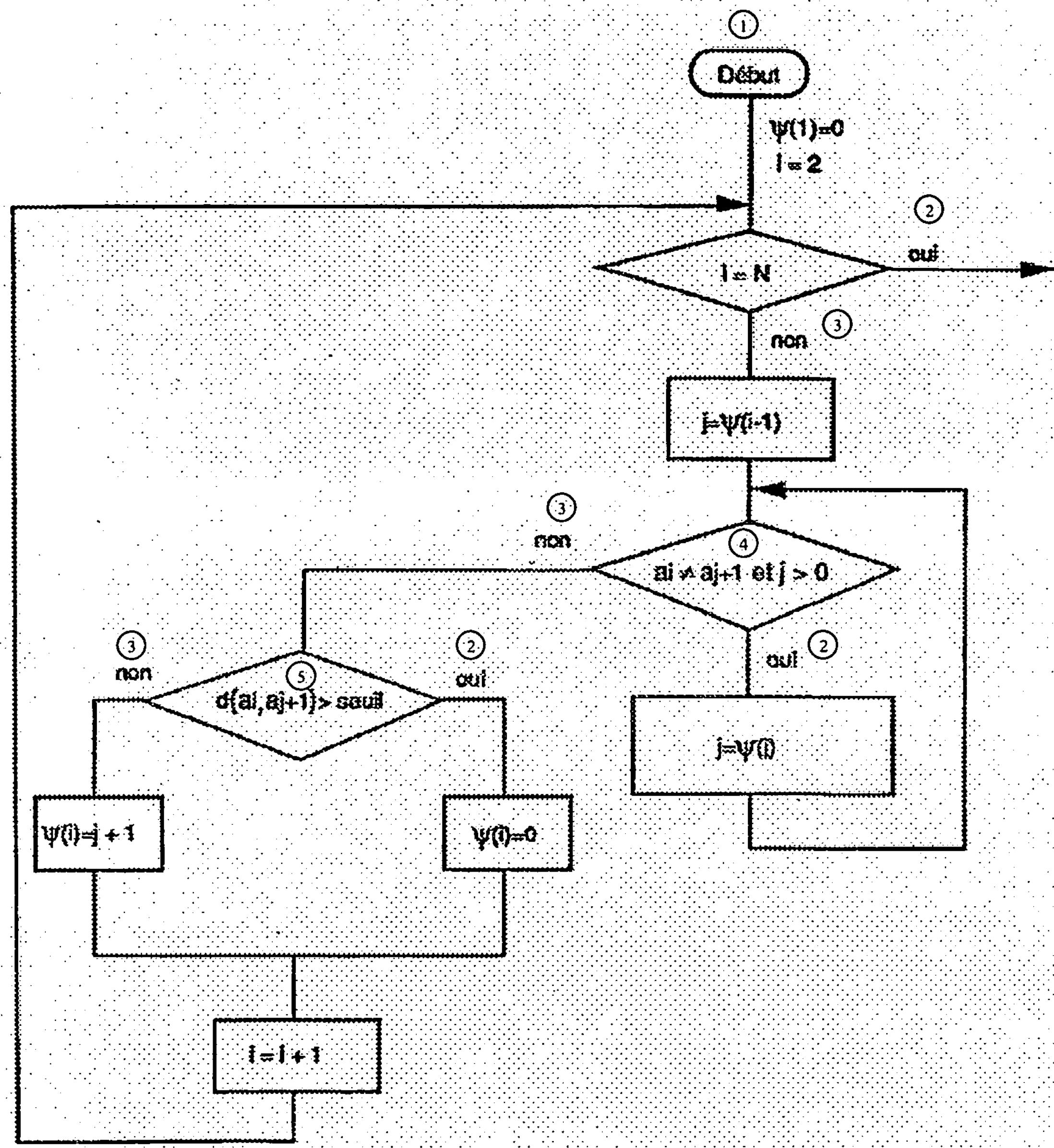


Fig.13

Key:

1	Start
2	Yes
3	No
4	and
5	d(ai,aj+1) > threshold

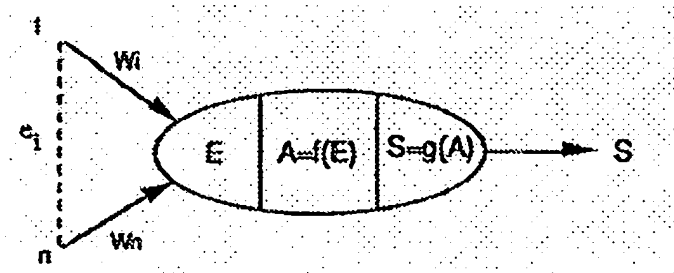


Fig.14

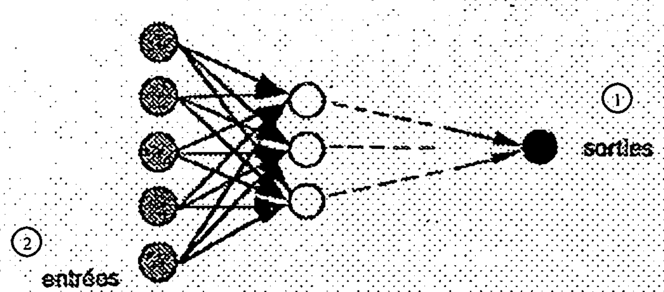


Fig.15

Key: 1 Outputs
2 Inputs

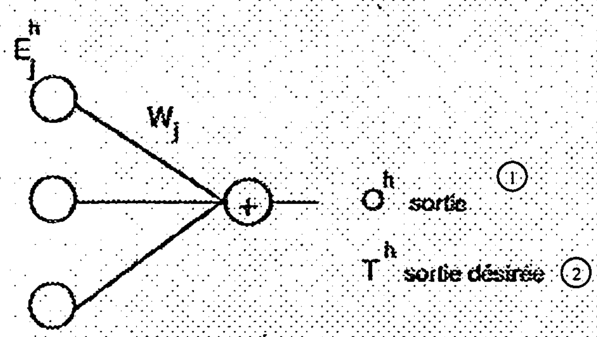


Fig.16

Key: 1 Output
2 Desired output

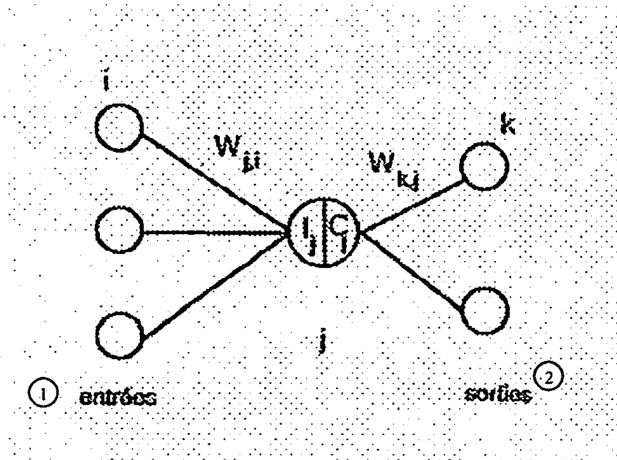


Fig.17

Key: 1 Input
2 Outputs

Fig. 18-1

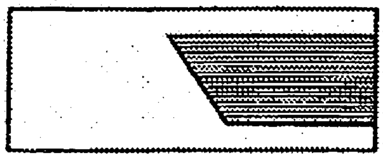


Fig. 18-2

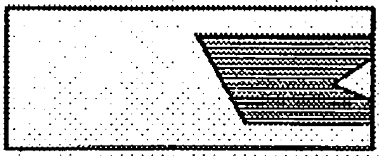


Fig. 18-3

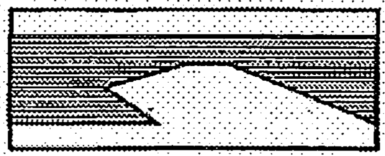


Fig. 18-4

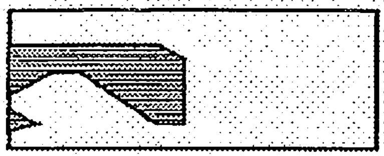


Fig. 18-5

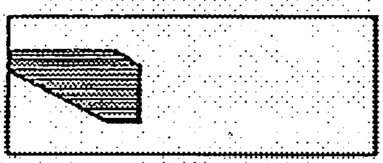


Fig. 18-6

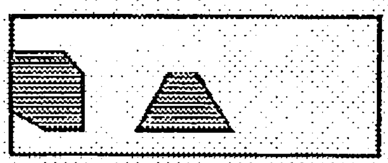


Fig. 18-7

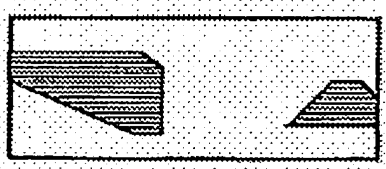


Fig. 18-8

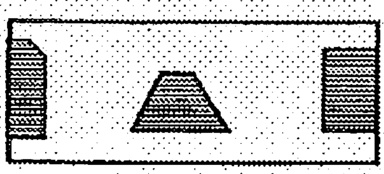


Fig. 18-9

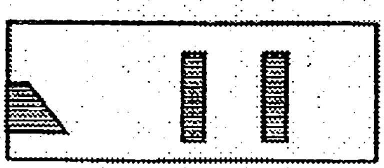


Fig. 18-10

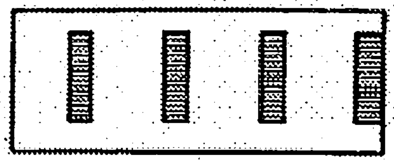


Fig. 18-11

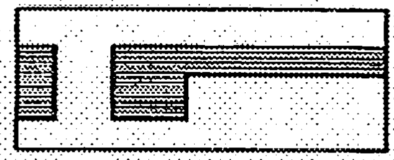


Fig. 18-12

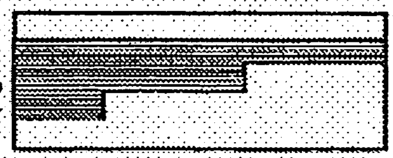


Fig. 18-13

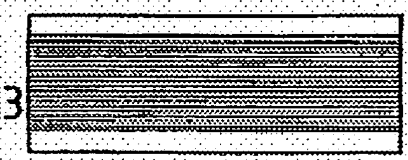


Fig. 18-14

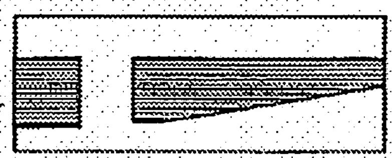


Fig. 18-15

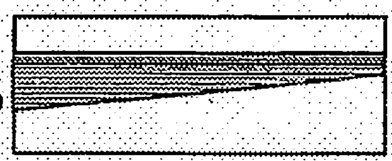


Fig. 18-16

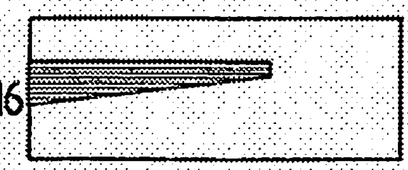


Fig. 18-17

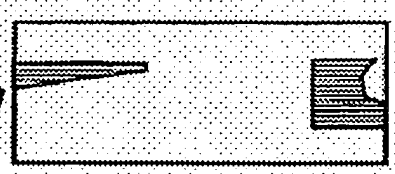


Fig. 18-18

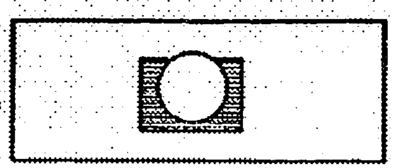


Fig. 19-1

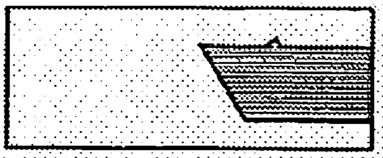


Fig. 19-2

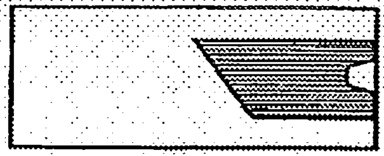


Fig. 19-3

Fig. 19-4

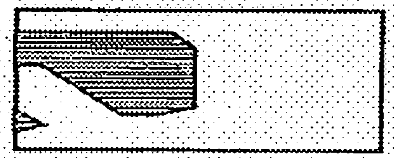


Fig. 19-5

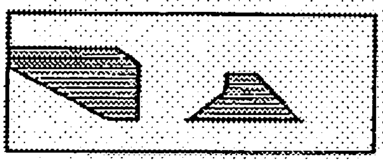


Fig. 19-6

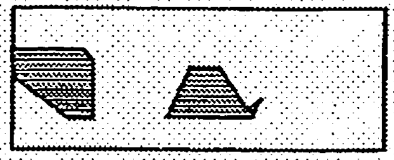


Fig. 19-7

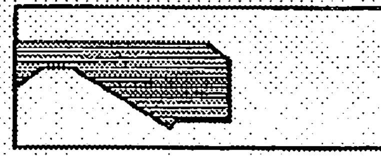
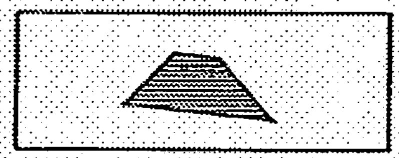


Fig. 19-8

Fig. 19-9



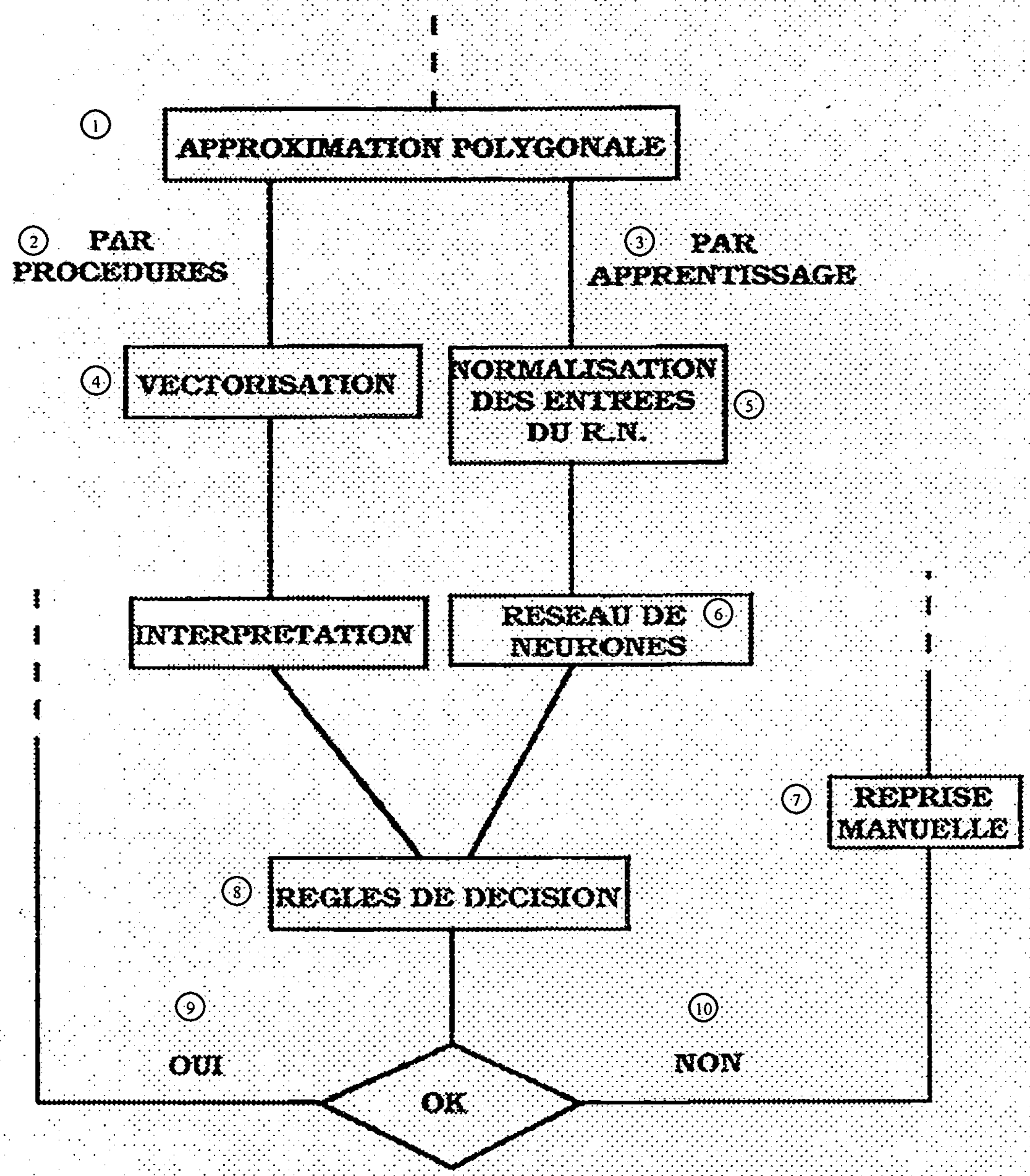


Fig.20

Key:

1	Polygonal approximation
2	By procedures
3	By learning
4	Vectorization
5	Normalization of the inputs of the R.N. [N.N. neuronal network]
6	Neuronal network

7	Manual resumption
8	Decision rules
9	Yes
10	No

FRENCH REPUBLIC
National Institute
of Industrial Property

Application Number
FR 9201339
FA 470592

SEARCH REPORT
established on the basis of the most recent claims filed before the start of the search

DOCUMENTS CONSIDERED TO BE RELEVANT		Claims concerned in the examined document
Category	Citation of document with indication where appropriate, of relevant passages	
Y	PATTERN RECOGNITION. Vol. 22, No. 5, 1989, OXFORD, GB Pages 567-575, XP46532 MIN-HONG HAN ET AL. 'INSPECTION OF 2-D OBJECTS USING PATTERN MATCHING METHOD' * Chapters 1, 2 * ---	1
Y	US-A-4 773 098 (SCOTT) * Column 12, line 45 – column 14, line 68; Figures 9-13 * ---	1
A	COMPUTER VISION GRAPHICS AND IMAGE PROCESSING Vol. 29, No. 2, February 1985, DULUTH, MA US Pages 216-247 F. ETESMI 'Automatic Dimensional Inspection of Machine Part Cross-Sections Using Fourier Analysis' * Abstract * ---	2,3
A	IEEE REGION 5 CONFERENCE 1988: SCANNING THE PEAKS OF ELECTROTECHNOLOGY, MARCH 21-23, 1988 COLORADO SPRINGS, COLORADO, USA, IEEE, NEW YORK, US Pages 187-191 L. B. MOOREHEAD ET AL. 'A NEURAL NETWORK FOR SHAPE RECOGNITION' * paragraph III-A * -----	2

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
G06K G06F

Date of completion of the search	Examiner
OCTOBER 29, 1992	Michiel Sonius

CATEGORY OF CITED DOCUMENTS

X: Particularly relevant if taken alone.
Y: Particularly relevant if combined with another document of the same category.
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O: Non-written disclosure.
P: Intermediate document.
T: Theory or principle underlying the invention.
E: Earlier patent document, but published on, or after the filing date.
D: Document cited in the application.
L: Document cited for other reasons.

&: Member of the same patent family, corresponding document.